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The Biomechanics of Balloon Kyphoplasty

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SUMMARY

Treating fractures of the spine is a major challenge for the medical community both within Ireland and Internationally with an estimated **1.4 million fractures per annum worldwide** [Johnell 2006]. Treatment options for these fractures have evolved from simple bed rest through to modern minimally invasive cementation techniques. **Balloon Kyphoplasty** is one such **minimally invasive treatment** that uses an inflatable bone tamp to restore the height of collapsed vertebrae, followed by cement injection to stabilise the structure (Figure 1).

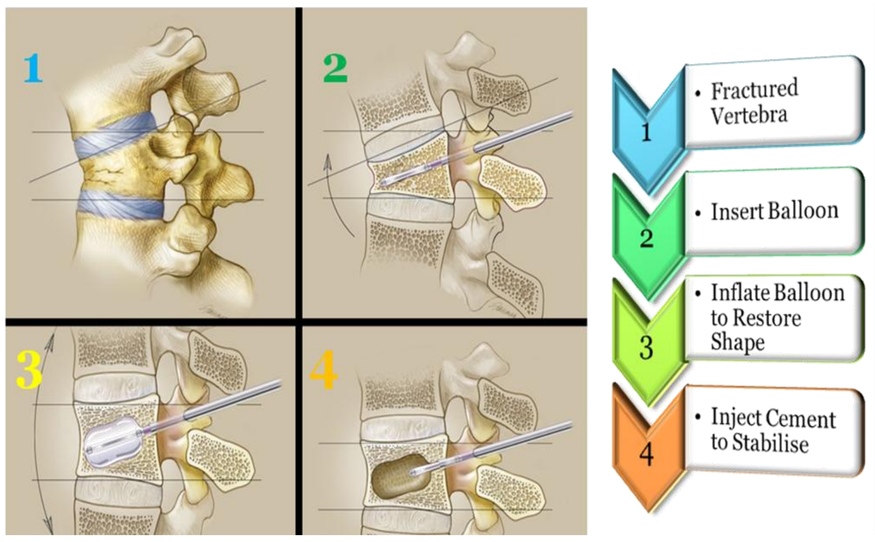

Figure 1

An Irish study [Lenehan 2009] of ~1,000 admissions during a 5-year period found traumatic spinal injuries needed on average **46 days of hospital admission** along with life-long monitoring in cases of spinal cord injury. **Costs for life-long treatment** of a 25-year old with spinal cord injury has been estimated at **€2.9 million** [NSCISC 2012].

A recent clinical study [Kim 2012] of 175 patients drew attention to the **significance of the bone-cement interface** region following Kyphoplasty. The current work hypothesised that mechanical loading at the bone-cement interface is altered by the changing load angle induced by vertebral height loss.

METHODS

A **validated finite element model** [Tyndyk 2007] of a human thoracolumbar spine was segmented into a single **L1 vertebral body** and modified to replicate bilateral Balloon Kyphoplasty (Figure 2). Cement was modeled using prolate spheroids surrounded by an **interface region divided into anterior, middle and posterior sections**. Interface thickness was calculated using a previously developed mathematical model with a bone volume fraction of 0.3 and 50% bone compaction [Purcell 2012, 2013]. An 800N [Tyndyk 2005] **load was applied at angles of 0° and 20°** [Aquarius 2011] to represent the loading conditions during rehabilitation after the Kyphoplasty procedure.

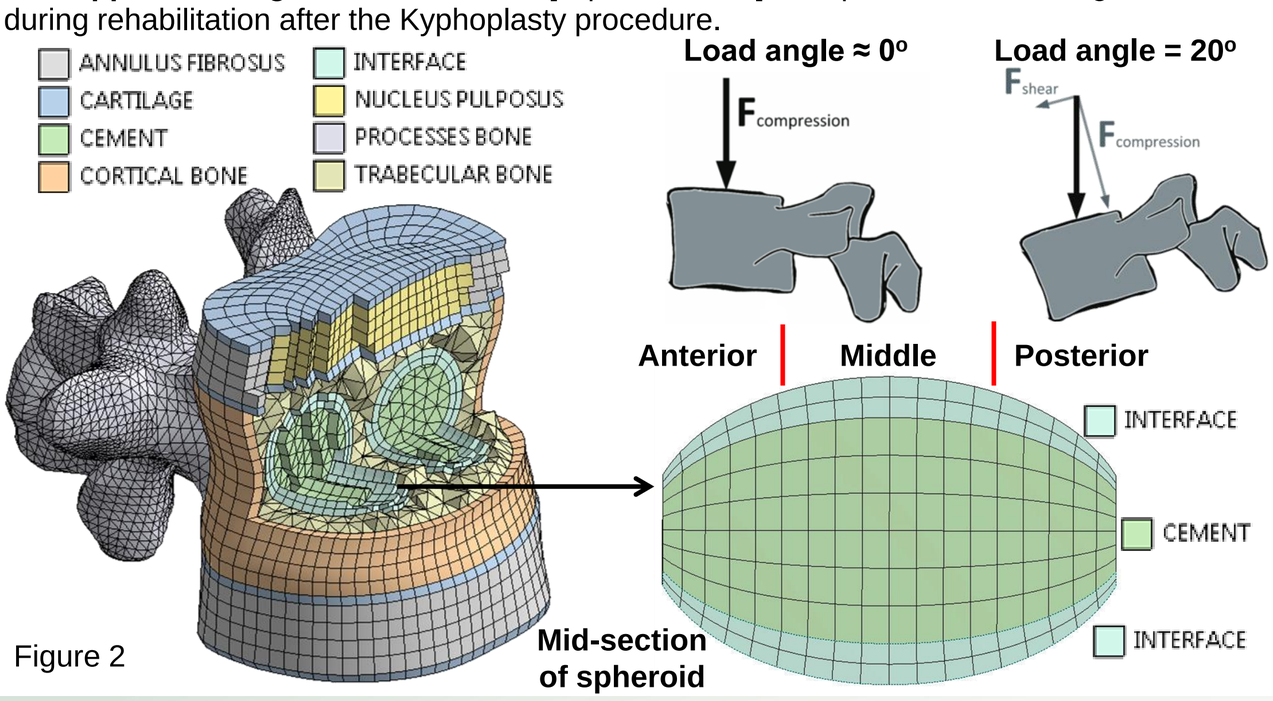

Figure 2

RESULTS

Results indicate that increased Kyphotic loading causes a **shift in stress distribution to the posterior parts of the interface region by up to 34-44%** (Figure 3). The anterior and middle sections of the interface experienced changes in average Von Mises stress of less than 11%. Maximum Von Mises stresses were not strongly influenced by the altered loading angle and increased by up to 7% in the posterior section of the interface region.

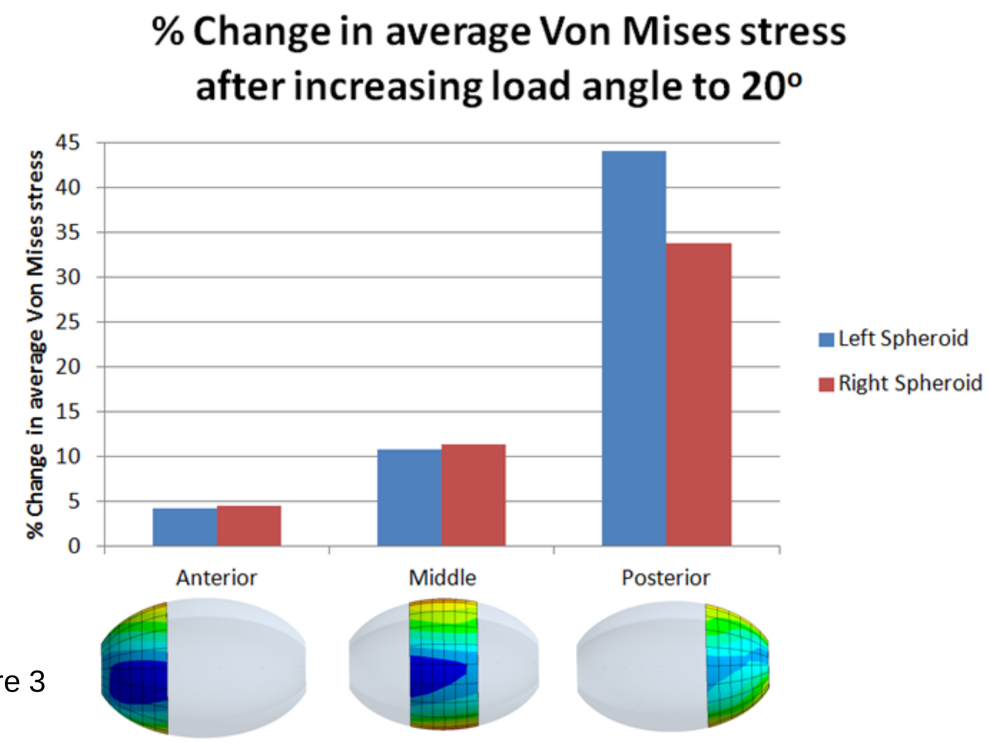

Figure 3

DISCUSSION & FUTURE WORK

The results show that **height loss induced load changes initiate a shift in stress distribution** to the posterior parts of the interface region. Further investigation of the stress states found **significant compressive stresses are imposed on the posterior parts of the interface** region due to the transmission of shear loads through the pedicles caused by Kyphosis. This demonstrates that **height loss and interface loading are strongly interdependent** and can contribute to sustaining a cycle of increased interfacial stresses leading to further vertebral collapse.

Applying these findings in the context of Kyphoplasty, where poor cement interdigitation is prevalent [Kruger 2012], indicates an increased likelihood of sliding at the contact points between the bone and cement. It has been shown [Zhao 2012] that **localized deformation** at bone-cement contact sites constitute a significant proportion of the deformation seen in the interface region. The increased loading in the posterior parts of the interface carries additional significance in a clinical context since the cement bolus in this region often contains an **imprint from the cannula** used by the surgeon and can act as a site for crack formation.

Investigations into **alternative surgical devices and techniques** is ongoing to address shortcomings in the present treatment strategies. These investigations have highlighted **multiple** opportunities for **product innovations** with the potential to improve patient outcomes and reduce costs for healthcare providers.

ACKNOWLEDGEMENTS

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